"Indoor Radon and Radon Decay Product Measurement Device Protocols"

U.S. Environmental Protection Agency
Office of Air and Radiation (6604J)
EPA 402-R-92-004, July 1992 (revised)

Table of Contents

Please Note:

EPA closed its National Radon Proficiency Program (RPP) in 1998. Please check our proficiency page for more information on how to find a qualified radon service professional. The information in this document which refer to companies, individuals or test devices that "meet EPA's requirements", or "EPA Certified...", or refers to EPA's old RPP designations "RMP or RCP" is no longer applicable. This document is in need of revision to reflect the closure of EPA's old RPP. Our proficiency page has information how to find qualified radon service professionals.

Disclaimer

While we try to keep the information timely and accurate, we make no expressed or implied guarantees. We will make every effort to correct errors brought to our attention. The material and descriptions compiled for these pages are not to be considered Agency guidance, policy, or any part of any rule-making effort but are provided for informational and discussion purposes only. They are not intended, nor can they be relied upon, to create any rights enforceable by any party in litigation with the United States.

Acknowledgements

This document represents the cumulative efforts of many dedicated individuals within the radon measurement community and the U.S. Environmental Protection Agency. Several key components of this document were prepared by the authors acting as interpreters of the substantial field experience and technical knowledge provided by these individuals, and their assistance is gratefully acknowledged.

Significant Changes in this Revision

This protocol document updates and supersedes the U.S. Environmental Protection Agency (EPA) document entitled, "Indoor Radon and Radon Decay Product Measurement Protocols," and issued in March, 1989 (U.S. EPA 1989a). The updating reflects new information, new procedures, and new measurement devices, including a new interim protocol for unfiltered track detectors. The EPA's testing recommendations are summarized in Section 1.2. This measurement strategy reflects the changes made in the most recent edition of "A Citizen's Guide to Radon" (U.S. EPA 1992a). More information is also provided in the EPA measurement guidance document, "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c). Guidance on radon measurements in schools and for real estate transactions is also available (U.S. EPA 1989b, 1992b).

This edition contains some clarifications and new information on quality assurance. The addition of a Glossary provides definitions and formulas for several of the technical terms used in the document, including accuracy, precision, and the values used to quantify these parameters.

The two previous editions of these protocols (U.S. EPA 1986, 1989a) used the value coefficient of variation (COV), defined as the standard deviation divided by the mean, as the expression used for the goal (at 4 pCi/L or 0.02 WL) of 10 percent for precision. The COV should decrease with increasing concentration. This edition explains that there is a variety of ways to calculate and express precision, including the COV and the relative percent difference, defined as the difference between two duplicates divided by their mean. It is important to monitor precision over the entire range of radon levels that are encountered routinely in the measurement program, and that a systematic and documented method for evaluating changes in precision be part of the standard operating procedures. While a limited precision error is desirable (e.g., COV of $\leq$ 10% at 4 pCi/L), it is most important to maintain the total error of any individual device (including both errors in precision and accuracy) to within ± 25 percent of the "true" radon or decay product concentration for concentrations at or above 4 pCi/L (0.02 Working Levels when the equilibrium ratio is 0.5).

To limit errors in accuracy, this edition recommends that users calibrate their measurement systems at least once every 12 months. Participation in the former National Radon Measurement Proficiency (RMP) Program did not satisfy the need for annual calibration, as this Program was a performance test, not a calibration procedure.

The 1986 and 1989 versions of the measurement protocols recommended that known exposure measurements, or spikes, be conducted at a rate of a few percent of the total number of measurements. These measurements are those for which the detectors are exposed to a known radon concentration in a calibration chamber and analyzed routinely. The results are used to monitor the accuracy of the entire system. This edition clarifies this recommendation, specifying that spikes be conducted at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. This reduces the number of spikes necessary for large users and clarifies the need for spikes by all users.

A significant change in this version of the Measurement Protocols is the requirement that all devices used for measurements in homes, schools, or workplaces be deployed for a minimum of 48 contiguous hours. It is important to understand that this minimum measurement period applies to all cases when the result of the measurement is given to a homeowner or building official to determine the need for further measurements or remedial action. The exceptions to the 48-hour measurement period are for those cases when the results will not be reported to a homeowner or building official, but will be used by a mitigator or researcher within the context of their project or research. For example, in-progress diagnostic measurements made in the process of performing mitigation can help to determine points of radon influx. Results of these measurements will be used to assist the contractor to better understand the dynamics of radon within that building, and will be part of a series of measurements, including pre- and post-mitigation 48-hour measurements. Radon researchers testing the effects of mitigation techniques, measurements methods, or strategies may also need to perform measurements of flexible durations.

The Agency has implemented a requirement for a minimum measurement period for several reasons. First, it will help ensure consistency among measurement programs, thereby ensuring that measurement results of at least a minimum quality become the basis for decisions by homeowners, school officials, and others responsible for authorizing further measurements or mitigation. This will become increasingly important as radon is measured in more and different types of buildings, and as a more diverse group of people, many without technical backgrounds, find the need to compare and understand these results. Second, a minimum measurement period will guarantee that a certain number of hours, including daily radon cycles, will be incorporated into the result reported to the persons responsible for making a decision about that building.

A period of 48 hours for the minimum measurement period is a policy decision that was arrived at after careful scrutiny of the possible options. It is important that the complete measurement result includes the effects of daily fluctuations in radon levels, so the minimum period needed to be a multiple of a 24-hour day. The Agency deems a single 24-hour period as too short because of the possibility of unforeseen circumstances occurring during the 24 hours; this possibility is diminished if two 24-hour periods form the duration of the measurement. One possible unforeseen circumstance is the improper implementation of closed-building conditions. A longer measurement period increases the chance of identifying such occurrences and helps minimize their impact. Finally, it was deemed important to include two daily cycles so that periods of low and high radon concentrations are well represented in the overall result.

There may be some situations when it is impossible to terminate the measurement at exactly 48 hours; therefore, a grace period of two hours will be allowed. A measurement made over a period of at least 46 hours is sufficient and is considered a two-day measurement. This grace period applies to all measurement methods.

Concerns have been raised regarding the requirement of a minimum distance of 30 inches from the floor for placement of detectors. The change from 20 inches to 30 inches was made in the March 1989 Protocols (U.S. EPA 1989a). This distance is not thought to be critical, so this version again recommends a minimum distance of at least 20 inches. In addition, the 1989 edition was not specific regarding the minimum distance between the measurement location and an exterior wall; this revision clarifies that distance to be about one meter, or three feet. Suspended detectors should also be about six to eight feet above the floor (i.e., within the general breathing zone).

Sections 2.6 (Evacuated Scintillation Cells), 2.7 (Pump/Collapsible Bags), and 2.8 (Radon Grab Sampling) of the previous protocol document (U.S. EPA 1989a) describe methods that share common features. For this reason, the three measurement methods are combined into one section in this revision. In addition, the Appendices A and B of the previous document are now part of their corresponding protocols. The radon grab sampling and pump/collapsible bags methods are not appropriate for purposes of determining the need for further measurements or for mitigation because they do not comply with the 48-hour minimum measurement period.

This revision also reflects the method designations used in the former National Radon Proficiency (RPP) Program. A two letter code for each method has been adopted, although ATDs (AT), RPISUs (RP), and EICs/ECs (ES or EL) may still be referred to by their traditional acronyms. The current designations are as follows:

Radon and Radon Decay Product Measurement Methods

METHOD CATEGORY	Abbreviations	
	Common Designation	Protocol Designation
Continuous Radon Monitors	CRM	CR
Alpha Track Detectors	ATD	AT
Electret Ion Chambers Short Term Long Term	EIC/EC	 ES EL
Activated Charcoal Adsorption Devices (formerly called charcoal canisters)	CC	AC
Charcoal Liquid Scintillation	CLS	LS
Three-day Integrating Evacuated Scintillation Cells		SC
Pump/Collapsible Bag Devices (24 hour sample)		PB

Grab Radon Sampling Scintillation Cells Activated Charcoal Pump-Collapsible Bag		 GS GC GB
Unfiltered Track Detectors	UTD	UT
Continuous Working Level Monitors	CWLM	CW
Radon Progeny Integrating Sampling Units	RPISU	RP
Grab Sampling - Working Level		GW

Go to Section One

Go to top

Where You Live
A to Z Index
Radon Frequent Questions
Radon Publications
Radon Hotlines
Radon Myths and Facts
Radon Risk Chart
Radon Action Month
Find a Qualified Radon Professional
Radon and Real Estate
Radon in Water
Radon Resistant New Construction (RRNC)
EPA Map of Radon Zones
BEIR VI Report on Radon
Radon Public Service Announcement (PSA)
Radon Links

"Indoor Radon and Radon Decay Product Measurement Device Protocols"

Section 1: General Considerations

Table of Contents

1.1 Introduction and Background

The risk of lung cancer due to exposure to radon and its decay products is of concern to State and Federal health officials. There is increased awareness that indoor radon concentrations may pose a significant health threat, and that there are areas in the country where some indoor levels are such that even short-term exposures can cause a significant increase in risk. It is extremely important that homes and other buildings be tested to determine if elevated radon levels are present indoors. However, in the process, the collection of unreliable or misleading data must be avoided.

There are many Federal, State, university, and private organizations now performing measurements or planning measurement programs. It is important for these different groups to follow consistent procedures to assure accurate and reproducible measurements, and to enable valid intercomparison of measurement results from different studies.

The objective of this document is to provide information, recommendations, and technological guidance for anyone providing measurement services using 15 radon and radon decay product measurement methods. The EPA has evaluated these techniques and found them to be satisfactory. However, the Agency has not conducted large-scale field tests using the unfiltered track detection technique, and an interim protocol has been prepared with the assistance of researchers who have field experience with this method. As the EPA and others acquire more experience with this interim technique, the guidelines may be revised.

These Protocols provide method-specific technological guidance that can be used as the basis for standard operating procedures. In keeping with good laboratory practices, each radon measurement company should develop its own detailed instrument-specific procedures that incorporate recommendations found in this and other radon-related EPA protocol and guidance documents. Mere duplication of sections of this report will not constitute an adequate standard operating procedure.

The recommendations contained in this report are similar to those being developed by industry and other groups (e.g., the American Society of Testing and Materials [ASTM 1991] and the American Association of Radon Scientists and Technologists [AARST 1991a]). This report is a guidance document; however, one condition of participation in EPA's former National Radon Proficiency Program (RPP) was conformance with these protocols.

Go to top

1.2 General Guidance on Measurement Strategy, Measurement Conditions, Device Location Selection, and Documentation

1.2.1 Measurement Strategy

The choice of measurement strategy depends upon the purpose of the radon measurement and the type of building where the measurement is made, such as a home, school or workplace. EPA's recommendations for measuring radon in various situations are outlined in documents such as the second edition of "A Citizen's Guide to Radon" (U.S. EPA 1992a), the EPA "Home Buyer's and Seller's Guide to Radon" (U.S. EPA 1992b), the "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c), and in "Radon Measurements in Schools" (EPA Document #402-R-92-014, revised July 1993). The following discussion on measurement conditions, device location selection, and documentation apply to measurements made in all types of buildings.

1.2.2 Measurement Conditions

The following conditions should exist prior to and during a measurement period to standardize the measurement conditions as much as possible. This list may be applied to each of the measurement methods discussed in Sections 2 and 3. However, there may also be method-specific conditions that are mentioned in the applicable protocol.

Short-term measurements lasting 90 days or less should be made under closed-building conditions. To the extent reasonable, all windows, outside vents, and external doors should be closed (except for normal entrance and exit) for 12 hours prior to and during the measurement period. Normal entrance and exit includes opening and closing a door, but an external door should not be left open for more than a few minutes. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason, short-term measurements should be made during winter periods whenever possible.

In addition to maintaining closed-building conditions during the measurement, closed-building conditions for 12 hours prior to the initiation of the measurement are a required condition for measurements lasting less than four days, and are recommended prior to measurements of up to a week in duration.

Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operating during measurements and for at least 12 hours before measurements are initiated. Air conditioning systems that recycle interior air may be operating. Normal operation of permanently installed air-to-air heat exchangers may also continue during closed-building conditions.

In buildings where permanent radon mitigation systems have been installed, these systems should be functioning during the measurement period.

Short-term tests lasting just two or three days should not be conducted if severe storms with high winds (e.g., > 30 mph) or rapidly changing barometric pressure are predicted during the measurement period. Weather predictions available on local news stations can provide sufficient information to determine if these conditions are likely.

In southern climates, or when measurements must be made during a warm season, the closed-building conditions are satisfied by meeting the criteria listed above. The closed-building conditions must be verified and maintained more rigorously, however, when they are not the normal living conditions.

1.2.3 Measurement Device Location Selection

The following criteria should be applied to select the location of the detector within a room. For further guidance on selecting an appropriate area in a building in which to place the measurement device, the reader should refer to the relevant documents mentioned in section 1.2.1. The following list may be applied to each of the measurement methods discussed in Sections 2 and 3. However, there may be method-specific location criteria that will be mentioned in the applicable protocol.

A position should be selected where the detector will not be disturbed during the measurement period and where there is adequate room for the device.

The measurement should not be made near drafts caused by heating, ventilating and air conditioning vents, doors, fans, and windows. Locations near excessive heat, such as fireplaces or in direct sunlight, and areas of high humidity should be avoided.

The measurement location should not be within 90 centimeters (3 feet) of windows or other potential openings in the exterior wall. If there are no potential openings (e.g., windows) in the exterior wall, then the measurement location should not be within 30 centimeters (1 foot) of the exterior walls of the building.

The detector should be at least 50 centimeters (20 inches) from the floor, and at least 10 centimeters (4 inches) from other objects. For those detectors that may be suspended, an optimal height for placement is in the general breathing zone, such as 2 to 2.5 meters (about 6 to 8 feet) from the floor.

In general, measurements should not be made in kitchens, laundry rooms, closets, or bathrooms.

1.2.4 Documentation

The operator of the measurement device must record enough information about the measurement in a permanent log so that data interpretation and comparison can be made.

The results of radon decay product measurements should be reported in Working Levels (WL). If the WL value is converted to a radon concentration which is also reported to a homeowner, it should be stated that this approximate conversion is based on a 50 percent equilibrium ratio. In addition, the report should indicate that this ratio is typical of the home environment, but any indoor environment (especially in schools and workplaces) may have a different and varying relationship between radon and decay products.

The following list may be applied to each of the measurement methods discussed in Sections 2 and 3. However, there may be method-specific documentation requirements that will be mentioned in the applicable protocol.

The start and stop times and dates of the measurement;

Whether the standardized measurement conditions, as discussed in Section 1.2.2, are satisfied;

The exact location of the device, on a diagram of the room and building if possible;

Other easily obtained information that may be useful, such as the type of building and heating system, the existence of a crawl space or basement, the occupants' smoking habits, and the operation of humidifiers, air filters, electrostatic precipitators, and clothes dryers;

The serial number and manufacturer of the detector, along with the code number or description which uniquely identifies customer, building, room, and sampling position; and

The condition (open or closed) of any crawl space vents.

Go to top

1.3 Quality Assurance

The objective of quality assurance is to ensure that data are scientifically sound and of known precision and accuracy. This section discusses the four general categories of quality control measurements; specific guidance is provided for each method in the relevant section.

Anyone providing measurement services using radon and radon decay product measurement devices should establish and maintain quality assurance programs. These programs should include written procedures for attaining quality assurance objectives and a system for recording and monitoring the results of the quality assurance measurements described below. The EPA offers general guidance on preparing quality assurance plans (U.S. EPA 1980); a draft standard prepared by a radon industry group is also available (AARST 1991b). The quality assurance program should include the maintenance of control charts and related statistical data, as described by Goldin (Goldin 1984) and by the EPA (U.S. EPA 1984).

1.3.1 Calibration Measurements

Calibration measurements are samples collected or measurements made in a known radon environment, such as a calibration chamber. Detectors requiring analysis, such as charcoal canisters, alpha track detectors, electret ion chambers, and radon progeny integrating samplers, are exposed in a calibration chamber and then analyzed. Instruments providing immediate results, such as continuous working level and radon monitors, should be operated in a chamber to establish individual instrument calibration factors.

Calibration measurements must be conducted to determine and verify the conversion factors used to derive the concentration results. These factors are determined normally for a range of concentrations and exposure times, and for a range of other exposure and/or analysis conditions pertinent to the particular device. Determination of these calibration factors is a necessary part of the laboratory analysis, and is the responsibility of the analysis laboratory. These calibration measurement procedures, including the frequency of tests and the number of devices to be tested, should be specified in the quality assurance program maintained by manufacturers and analysis laboratories.

Known exposure measurements or spiked samples consist of detectors that have been exposed to known concentrations in a radon calibration chamber. These detectors are labeled and submitted to the laboratory in the same manner as ordinary samples to preclude special processing. The results of these measurements are used to monitor the accuracy of the entire measurement system. Suppliers and analysis laboratories should provide for the blind introduction of spiked samples into their measurement processes and the monitoring of the results in their quality assurance programs. Providers of passive measurement devices should conduct spiked measurements at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. Providers of measurements with active devices are required to recalibrate their instruments at least once every 12 months. Participation in EPA's former National Radon Proficiency Program (RPP) did not satisfy the need for annual calibration, as this Program was a performance test, not a calibration procedure.

1.3.2 Background Measurements

Background measurements are required both for continuous monitors and for passive detectors requiring laboratory analysis. Users of continuous monitors must perform sufficient instrument background measurements to establish a reliable instrument background and to act as a check on instrument operation.

Passive detectors requiring laboratory analysis require one type of background measurement made in the laboratory and another in the field. Suppliers and analysis laboratories should measure routinely the background of a statistically significant number of unexposed detectors from each batch or lot to establish the laboratory background for the batch and the entire measurement system. This laboratory blank value is subtracted routinely (by the laboratory) from the field sample results reported to the user, and should be made available to the users for quality assurance purposes. In addition to these background measurements, the organization performing the measurements should calculate the lower limit of detection (LLD) for its measurement system (Altshuler and Pasternack 1963, ANSI 1989, U.S. DOE 1990). This LLD is based on the detector and analysis system's background and can restrict the ability of some measurement systems to measure low concentrations.

Providers of passive detectors should employ field controls (called blanks) equal to approximately five percent of the detectors that are deployed, or 25 each month, whichever is smaller. These controls should be set aside from each detector shipment, kept sealed and in a low radon environment, labeled in the same manner as the field samples to preclude special processing, and returned to the analysis laboratory along with each shipment. These field blanks measure the background exposure that may accumulate during shipment and storage, and the results should be monitored and recorded. The recommended action to be taken if the concentrations measured by one or more of the field blanks is significantly greater than the LLD is dependent upon the type of detector and is discussed in the section for each method.

1.3.3 Duplicate (Collocated) Measurements

Duplicate measurements provide a check on the quality of the measurement result, and allow the user to make an estimate of the relative precision. Large precision errors may be caused by detector manufacture or improper data transcription or handling by suppliers, laboratories, or technicians performing placements. Precision error can be an important component of the overall error, so it is important that all users monitor precision.

Duplicate measurements should be side-by-side measurements made in at least 10 percent of the total number of measurement locations, or 50 each month, whichever is smaller. The locations selected for duplication should be distributed systematically throughout the entire population of samples. Groups selling measurements to homeowners can do this by providing two measurements, instead of one, to a random selection of purchasers, with the measurements made side-by-side. As with spiked samples introduced into the system as blind measurements, the precision of duplicate measurements should be monitored and recorded in the quality assurance records. The analysis of data from duplicates should follow the methodology described by Goldin in section 5.3 of his report and plotted on range control charts (Goldin 1984, U.S. EPA 1984). If the precision estimated by the user is not within the precision expected of the measurement method, the problem should be reported to the analysis laboratory and the cause investigated.

1.3.4 Routine Instrument Performance Checks

Proper functioning of analysis equipment and operator usage require that the equipment and measurement system be subject to routine checks. Regular monitoring of equipment and operators is vital to ensure consistently accurate results. Performance checks of analysis equipment includes the frequent use of an instrument check source. In addition, important components of the device (such as a pump, battery, or electronics) should be checked regularly and the results noted in a log. Each user should develop methods for regularly monitoring (preferably daily) their measurement system, and for recording and reviewing results.

Please Note: The EPA established the National RMP Program (the program then became the National Radon Proficiency Program (RPP), which was closed on 9/30/98) under the Indoor Radon Abatement Act of 1988 (IRAA), was to enable participants to demonstrate their proficiency at measuring radon and radon decay product concentrations. One condition of successful participation in the former RPP was that the total error of any individual device (including both errors in precision and accuracy) be within ±25 percent of the "true" radon or radon decay product concentration at or above 4 pCi/L.

Go to Table of Contents | Go to Section Two

Go to top

"Indoor Radon and Radon Decay Product Measurement Device Protocols"

Section 2: Indoor Radon Measurement Device Protocols

Table of Contents

2.1 Protocol for Using Continuous Radon Monitors (CR) to Measure Indoor Radon Concentrations

2.1.1 Purpose

This protocol provides guidance for using continuous radon monitors (CR) to measure indoor radon concentrations accurately and to obtain reproducible results. Adherence to this protocol will help ensure uniformity among measurement programs and allow valid comparison of results. Measurements made in accordance with this protocol will produce results representative of closed-building conditions. Measurements made under closed-building conditions have a smaller variability and are more reproducible than measurements made when the building conditions are not controlled. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c) or other appropriate EPA measurement guidance documents.

2.1.2 Scope

This protocol covers, in general terms, the sample collection and analysis method, the equipment needed, and the quality control objectives of measurements made with CRs. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these guidelines should be directed to the U.S. Environmental Protection Agency.

2.1.3 Method

There are three general types of CR monitors covered by this protocol. In the first type, ambient air is sampled for radon in a scintillation cell after passing through a filter that removes radon decay products and dust. As the radon in the cell decays, the radon decay products plate out on the interior surface of the scintillation cell. Alpha particles produced by subsequent decays, or by the initial radon decay, strike the zinc sulfide coating on the inside of the scintillation cell, thereby producing scintillations. The scintillations are detected by a photomultiplier tube in the detector which generates electrical pulses. These pulses are processed by the detector electronics and the data are usually stored in the memory of the monitor where results are available for recall or transmission to a data logger or printer.

This type of CR monitor uses either a flow-through cell or a periodic-fill cell. In the flow-through cell, air is drawn continuously through the cell by a small pump. In the periodic-fill cell, air is drawn into the cell once during each pre-selected time interval; then the scintillations are counted and the cycle repeated. A third variation operates by radon diffusion through a filter area with the radon concentration in the cell varying with the radon concentration in the ambient air, after a small diffusion time lag. The concentrations measured by all three variations of cells lag the ambient radon concentrations because of the inherent delay in the radon decay product disintegration process.

A second type of CR monitor operates as an ionization chamber. Radon in the ambient air diffuses into the chamber through a filtered area so that the radon concentration in the chamber follows the radon concentration in the ambient air with some small time lag. Within the chamber, alpha particles emitted during the decay of radon atoms produce bursts of ions which are recorded as individual electrical pulses for each disintegration. These pulses are processed by the monitor electronics; the number of pulses counted is displayed usually on the monitor, and the data are available usually for processing by an optional data logger/printer.

A third type of CR monitor functions by allowing ambient air to diffuse through a filter into a detection chamber. As the radon decays, the alpha particles are counted using a solid-state silicon detector. The measured radon concentration in the chamber follows the radon concentration in the ambient air by a small time lag.

2.1.4 Equipment

Equipment required depends on the type and model of CR monitor used. Aged air or nitrogen must be available for introduction into the CR monitor to measure the background count rate during calibration. For scintillation cell-type CRs, sealed scintillation cells with a measured low background should be available as spare cells.

2.1.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The CR measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

2.1.5.1 Pre-Sampling Testing. Before and after each measurement, the CR monitor should be tested carefully according to manufacturer's directions to: Verify that the correct input parameters and the unit's clock or timer are set properly; and Verify the operation of the pump. Flow rates within the range of the manufacturer's specifications are satisfactory.

After every 1,000 hours of operation of scintillation cell-type CRs, the background count rate should be checked by purging the unit with clean, aged air or nitrogen in accordance with the procedures identified in the operating manual for the instrument. In addition, the background count rate of all CR types should be monitored more frequently by operating the instrument in a low radon environment.

Participation in a laboratory intercomparison program should be conducted initially and at least once every 12 months thereafter, and after equipment repair, to verify that the conversion factor used by the CR monitor is accurate. This is done by comparing the unit's response to a known radon concentration.

At this time, the correct operation of the pump should be verified. Participation in EPA's National Radon Proficiency Program (RPP) did not satisfy the need for annual calibration, as this Program was a performance test rather than an internal calibration.

2.1.6 Measurement Criteria

The reader should refer to Section 1.2.2 for the list of general conditions that must be met to ensure standardization of measurement conditions.

2.1.7 Deployment and Operation

2.1.7.1 Location Selection. The reader should refer to Section 1.2.3 for standard criteria that must be considered when choosing a measurement device location.

2.1.7.2 Operation. The CR monitor should be programmed to run continuously, recording periodically the radon concentration for at least 48 hours. Longer measurements may be required, depending on the CR type and radon level being measured. An increase in operating time decreases the uncertainty associated with using the measurement result to represent a longer-term average concentration.

Care should be taken to account for data that are produced before equilibrium conditions have been established in a flow-through cell. Generally, conditions stabilize after the first four hours. Measurements made prior to this time are low and should either be discarded or used to estimate radon concentrations using pre-established system constants (Busigin et al. 1979, Thomas 1972). If the first four hours of data from a 48-hour measurement are discarded, the remaining hours of data can be averaged and are sufficient to represent a two-day measurement.

2.1.8 Retrieval of Monitors

When the measurement is terminated, the operator should document the stop-date and -time and whether the closed-building conditions are still in effect.

2.1.9 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that must be documented.

The serial numbers of the CR monitor, scintillation cells, and other equipment must also be recorded.

2.1.10 Results

2.1.10.1 Sensitivity. Most CR monitors are capable of a lower limit of detection (LLD [calculated using methods described by Altshuler and Pasternack 1963]) of 1.0 picoCurie per liter (pCi/L) or less.

2.1.10.2 Precision. Most CR monitors can achieve a coefficient of variation of less than 10 percent at 4 pCi/L or greater. An alternate measure of precision is a relative percent difference, defined as the difference between two duplicate measurements divided by their mean; note that these two measures of precision are not identical quantities. It is important that precision be monitored continuously over a range of radon concentrations and that a systematic and documented method for evaluating changes in precision be part of the operating procedures.

2.1.11 Quality Assurance

The quality assurance program for CR measurements includes four parts: (1) calibration, (2) background measurements, (3) duplicate measurements, and (4) routine instrument checks. The purpose of a quality assurance program is to identify the accuracy and precision of the measurements and to ensure that the measurements are not influenced by exposure from sources outside the environment to be measured. The quality assurance program should include the maintenance of control charts (Goldin 1984); general information is also available (Taylor 1987, U.S. EPA 1984).

2.1.11.1 Calibration. Every CR monitor should be calibrated in a radon calibration chamber before being put into service, and after any repairs or modifications. (Note that an inherent element in the calibration process is a thorough determination of the background count rate using clean, aged air or nitrogen.) Subsequent recalibrations and background checks should be done at least once every 12 months, with cross-checks to a recently calibrated instrument at least semiannually. All cells need individual calibration factors.

2.1.11.2 Background Measurements. After every 1,000 hours of operation of scintillation cell-type CRs (about every 20th 48-hour measurement), and whenever any type of CR is calibrated, the background should be checked by purging the monitor with clean, aged air or nitrogen. In addition, the background count rate should be monitored more frequently by operating the instrument in a low radon environment. Cells which develop a high background after prolonged use should be reconditioned by the manufacturer.

2.1.11.3 Duplicate Measurements. When two or more CR monitors of the same type (e.g., scintillation cell, ionization chamber, or silicon detector types) are available, the precision of the measurements can be estimated by operating the monitors side-by-side. The analysis of duplicate results should follow the methodology described by Goldin (section 5.3 of Goldin 1984), by Taylor (Taylor 1987), or by the EPA (U.S. EPA 1984). Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

2.1.11.4 Routine Instrument Checks. Proper operation of all radiation counting instruments requires that their response to a reference source be constant to within established limits. Therefore, counting equipment should be subject to routine checks to ensure proper operation. This is achieved by counting an instrument check cell (for scintillation cell-type CRs) prior to beginning each measurement. The count rate of the check source should be high enough to yield good counting statistics in a short time (for example, 1,000 to 10,000 counts per minute).

If a check source is unavailable or incompatible with the type of CR monitor being used, an informal intercomparison with another measurement method that has proven reliability (for example in the EPA National RMP Program) should be conducted at least every tenth measurement. In addition, it is important to check regularly all components of the equipment that affect the result, including battery and electronics, and to document these checks.

Pumps and flow meters should be checked routinely to ensure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy.

Go to top

2.2 Protocol for Using Alpha Track Detectors (AT or ATD) to Measure Indoor Radon Concentrations

2.2.1 Purpose

This protocol provides guidance for using alpha track detectors (AT or ATD) to obtain accurate and reproducible measurements of indoor radon concentrations. Adherence to this protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c) or other appropriate EPA measurement guidance documents.

2.2.2 Scope

This protocol covers, in general terms, the equipment, procedures, and quality control objectives to be used in performing the measurements. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these guidelines should be directed to the U.S. Environmental Protection Agency.

2.2.3 Method

An AT consists of a small piece of plastic or film enclosed in a container with a filter-covered opening or similar design for excluding radon decay products. Radon diffuses into the container and alpha particles emitted by the radon and its decay products strike the detector and produce submicroscopic damage tracks. At the end of the measurement period, the detectors are returned to a laboratory. Plastic detectors are placed in a caustic solution that accentuates the damage tracks so they can be counted using a microscope or an automated counting system. The number of tracks per unit area is correlated to the radon concentration in air, using a conversion factor derived from data generated at a calibration facility. The number of tracks per unit of analyzed detector area produced per unit of time (minus the background) is proportional to the radon concentration. AT detectors function as true integrators and measure the average concentration over the exposure period.

Many factors contribute to the variability of AT results, including differences in the detector response within and between batches of plastic, non-uniform plate-out of decay products inside the detector holder, differences in the number of background tracks, and variations in etching conditions. Since the variability in AT results decreases with the number of net tracks counted, counting more tracks over a larger area of the detector, particularly at low exposures, will reduce the uncertainty of the result.

2.2.4 Equipment

ATs are available from commercial suppliers. These suppliers offer contract services in which they provide the detector and subsequent analysis and reporting for a fixed price. Establishing an in-house capability to provide packaged detectors, a calibration program, and an analysis program would probably not be practical or economically advantageous for most users. Therefore, details for establishing the analytical aspects of an AT program are omitted from this protocol. Additional details concerning AT programs have been reviewed elsewhere (Fleischer et al. 1965, Lovett 1969).

Assuming ATs are obtained from a commercial supplier, the following equipment is needed to initiate a measurement:

- An AT in an individual, sealed container (such as an aluminized plastic bag) to prevent extraneous exposure before deployment;
- A means to attach the AT to its measurement location, if it is to be hung from the wall or ceiling;
- An instruction sheet for the occupant, a sample log sheet, and a shipping container (along with a prepaid mailing label, if appropriate);
- Manufacturer instructions for resealing the detector at the time of retrieval and prior to returning it to the supplier for analysis; and
- A data collection log, if appropriate.

2.2.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The AT measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

The AT should not be deployed if the user's schedule prohibits terminating the measurement at the appropriate time.

2.2.6 Measurement Criteria

The reader should refer to Section 1.2.2 for the list of general conditions that must be met to ensure standardization of measurement conditions.

A 12-month AT measurement provides information about radon concentrations in a building during an entire year, so the closed-building conditions do not have to be satisfied to perform a valid year-long measurement.

2.2.7 Deployment

2.2.7.1 Location Selection. The reader should refer to Section 1.2.3 for standard criteria that must be considered when choosing a measurement device location.

If the detector is installed during a site visit, the final site selected should be shown to the building occupant to be certain it is acceptable for the duration of the measurement period.

2.2.7.2 Timely Deployment. A group of ATs should be deployed into houses as soon as possible after delivery from the supplier. In order to minimize chances of high background exposures, users should not order more ATs than they can reasonably expect to install within the following few months. If the storage time exceeds more than a few months, the background exposures from a sample of the stored detectors should be assessed to determine if they are different from the background of detectors that are not stored for long periods. The supplier's instructions regarding storage and background determination should be followed. This background assessment of detectors stored for long periods is not necessary if the analysis laboratory measures routinely the background of stored detectors, and if the stored detectors remain tightly sealed.

The sampling period begins when the protective cover or bag is removed. The edge of the bag must be cut carefully, or the cover removed, so that it can be reused to reseal the detector at the end of the exposure period. The detector and the radon-proof container should be inspected to make sure that they are intact and have not been physically damaged in shipment or handling.

2.2.8 Retrieval of Detectors

At the end of the measurement period (usually 90 days for short-term tests and one year for long-term measurements), the detector should be inspected for damage or deviation from the conditions entered in the log book at the time of deployment. Any changes should be noted in the log book. The time and date of removal should be entered on the data form for the detector and in the log book, if used. The detector should then be resealed following the instructions provided by the supplier. After retrieval, the detectors should be stored in a low radon environment and returned as soon as possible to the analytical laboratory for processing. In many cases, attempts at resealing ATs have not been totally successful, resulting in some continued exposure of the detectors beyond the deployment period. This extra exposure could bias the results high if the detectors are held for a significant length of time prior to analysis.

2.2.9 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that should be documented.

2.2.10 Analysis Requirements

2.2.10.1 Sensitivity. The lower limit of detection (LLD [calculated using methods described by Altshuler and Pasternack 1963]) is dependent upon the stability of the number of background tracks. Depending upon the system used, the background may be less variable if a greater area is analyzed. With present ATs, routine counting can achieve an LLD of 1 pCi/L-month, and an LLD of 0.2 pCi/L-month may be achieved by counting additional area.

2.2.10.2 Precision. The precision should be monitored using the results of the duplicate detectors described in Section 2.2.11.3 of this protocol, rather than a precision quoted by the manufacturer. The precision of an AT system is dependent upon the total number of tracks counted on the flank and test detector, and therefore the area of the detector that is analyzed. If few net tracks are counted, poor precision is obtained. Thus, it is important that the organization performing the measurement with an AT arranges for counting an adequate area or number of net tracks.

2.2.11 Quality Assurance

The quality assurance program for AT measurements involves five separate parts: (1) calibration, (2) known exposure measurements, (3) duplicate (collocated) detectors, (4) control detectors, and (5) routine instrument checks. The purpose of a quality assurance program is to identify the accuracy and precision of the measurements and to ensure that the measurements are not influenced by exposure from sources outside the environment to be measured. The quality assurance program should include the maintenance of control charts (Goldin 1984); general information is also available (Taylor 1987, U.S. EPA 1984).

2.2.11.1 Calibration. Every AT laboratory system should be calibrated in a radon calibration chamber at least once every 12 months. Determination of a calibration factor requires exposure of ATs to a known radon concentration in a radon exposure chamber. These calibration exposures are to be used to obtain or verify the conversion factor between net tracks per unit area and radon concentration. Participation in EPA's former National Radon Proficiency Program (RPP) did not satisfy the need for annual calibration, as this Program was a proficiency test rather than an internal calibration. The following guidance is provided to manufacturers and suppliers of AT services as minimum requirements in determining the calibration factor.

ATs should be exposed in a radon chamber at several different radon concentrations or exposure levels similar to those found in the tested buildings (a minimum of three different concentrations).

A minimum of 10 detectors should be exposed at each level.

A calibration factor should be determined for each batch or sheet of detector material received from the material supplier. Alternatively, calibration factors may be established from several sheets, and these factors extended to detectors from sheets exhibiting similar sensitivities (within pre-established tolerance limits).

2.2.11.2 Known Exposure Measurements. Anyone providing measurement services with AT devices should submit ATs with known radon exposures (spiked samples) for analysis at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. Known exposure (spiked) detectors should be labeled in the same manner as field detectors to ensure identical processing. The results of the spiked detector analyses should be monitored and recorded. Any significant deviation from the known concentration to which they were exposed should be investigated.

2.2.11.3 Duplicate (Collocated) Detectors. Anyone providing measurement services with AT devices should place duplicate detectors in enough houses to test the precision of the measurement. The number of duplicate detectors deployed should be approximately 10 percent of the number of detectors deployed each month or 50, whichever is smaller. The pair of detectors should be treated identically in every respect. They should be shipped, stored, opened, installed, removed, and processed together, and not identified as duplicates to the processing laboratory. The samples selected for duplication should be distributed systematically throughout the entire population of measurements. Groups selling measurements to homeowners can accomplish this by providing two detectors instead of one to a random selection of purchasers, with instructions to place the detectors side-by-side. Consideration should be given to providing some means to ensure that the duplicate devices are not separated during the measurement period. Data from duplicate detectors should be evaluated using the procedures described by Goldin (section 5.3 of Goldin 1984), by Taylor (Taylor 1987), or by the EPA (U.S. EPA 1984). Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

2.2.11.4 Control Detectors

2.2.11.4.1 Laboratory Control Detectors. The laboratory background level for each batch of ATs should be established by each laboratory or supplier. Suppliers should measure the background of a statistically significant number of unexposed ATs that have been processed according to their standard operating procedures. Normally, the analysis laboratory or supplier calculates the net readings (which are used to calculate the reported sample radon concentrations) by subtracting the laboratory blank values from the results obtained from the field detectors.

2.2.11.4.2 Field Control Detectors. Field control detectors must be a component of any AT measurement program. Field control ATs (field blanks) should consist of a minimum of five percent of the devices that are deployed every month or 25, whichever is smaller. Users should set these aside from each shipment, keep them sealed and in a low radon (less than 0.2 pCi/L) environment, label them in the same manner as the field ATs to assure identical processing, and send them back to the supplier with the field ATs for analysis. These control devices are necessary to measure the background exposure that accumulates during shipment and storage. The results should be monitored and recorded. If one or a few field blanks have concentrations significantly greater than the LLD established by the supplier, it may indicate defective packaging or handling. If the average value from the field control devices (field blanks) is significantly greater than the LLD established by the supplier, this average value should be subtracted from the individual values reported for the other devices in the exposure group.

It may be advisable to use three sets of detectors (pre-exposure, field, and post-exposure background) in order to allow the most thorough and complete evaluation of radon levels. For example, one group of detectors (pre-exposure detectors) may be earmarked for background measurement, and returned for processing immediately after the other detectors are deployed. The results from these detectors determine if the number of tracks acquired before deployment is significant and should be subtracted from the gross result. The second set of background detectors (post-exposure background detectors) are obtained just before the field monitors are to be collected, and are opened and kept in the same location as the returning field monitors for the same duration, and returned with them. Finally, this "post-exposure background" is subtracted from the field results, if found to be significant. In general, a value of 1 pCi/L or greater for any blank AT indicates a significant level that should be investigated, and potentially subtracted from the field AT results.

2.2.11.5 Routine Instrument Checks. Proper functioning of the analysis instruments and proper response by their operators require that the equipment be subject to routine checks. Daily or more frequent monitoring of equipment and operators is vital to ensuring consistently accurate results.

Go to top

2.3 Protocol for Using Electret Ion Chamber Radon Detectors (EC or ES, EL) to Measure Indoor Radon Concentrations

2.3.1 Purpose

This protocol provides guidance for using electret ion chamber radon detectors (EC) to obtain accurate and reproducible measurements of indoor radon concentrations. Adherence to this protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol can produce either short-term or long-term measurements, depending upon the type of EC employed. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c) or other appropriate EPA measurement guidance documents.

2.3.2 Scope

This protocol covers, in general terms, the equipment, procedures, and quality control objectives to be used in performing the measurements. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these guidelines should be directed to the U.S. Environmental Protection Agency.

2.3.3 Method

Short-term (ES) and long-term (EL) ECs have been described elsewhere (Kotrappa et al. 1988, 1990). They require no power, and function as true integrating detectors, measuring the average concentration during the measurement period.

The EC contains a charged electret (an electrostatically-charged disk of Teflon^{R}) which collects ions formed in the chamber by radiation emitted from radon and radon decay products. When the device is exposed, radon diffuses into the chamber through filtered openings. Ions which are generated continuously by the decay of radon and radon decay products are drawn to the surface of the electret and reduce its surface voltage. The amount of voltage reduction is related directly to the average radon concentration and the duration of the exposure period. ECs can be deployed for exposure periods of two days (one day for research purposes) to 12 months, depending upon the thickness of the electret and the volume of the ion chamber chosen for use. These deployment periods are flexible, and valid measurements can be made with other deployment periods depending on the application.

The electret must be removed from the EC chamber and the electret voltage measured with a special surface voltmeter both before and after exposure. To determine the average radon concentration during the exposure period, the difference between the initial and final voltages is divided first by a calibration factor and then by the number of exposure days. A background radon concentration equivalent of ambient gamma radiation is subtracted to compute radon concentration. Electret voltage measurements can be made in a laboratory or in the field.

2.3.4 Equipment

The following equipment is required to measure radon using the EC detection method:

- An EC of the type recommended for the anticipated exposure period and radon concentration (ES or EL);
- An instruction sheet for the user and a shipping container with a label for returning the detector(s) to the laboratory, if appropriate;
- A specially-built surface voltmeter for measuring electret voltages before and after exposure; and

- A data collection log.

2.3.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The ES or EL measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

The ES or EL should not be deployed if the user's schedule prohibits terminating the measurement at the appropriate time.

The ES or EL should be inspected prior to deployment to see that it has not been damaged during handling and shipping.

2.3.6 Measurement Criteria

The reader should refer to Section 1.2.2 for the list of general conditions that must be met to ensure standardization of measurement conditions.

A 12-month EL measurement provides information about radon concentrations during an entire year, so the closed-building conditions do not have to be satisfied to perform a valid year-long measurement.

2.3.7 Deployment

2.3.7.1 Location Selection. The reader should refer to Section 1.2.3 for standard criteria that must be considered when choosing a measurement device location.

2.3.7.2 Timely Deployment. Both ESs and ELs should be deployed as soon as possible after their initial voltage is measured. Until an ES or EL is deployed, an electret cover should remain in place over the electret to minimize voltage loss due to background radon and gamma radiation.

2.3.8 Retrieval of Detectors

The recommended deployment period for the very short-term ESs is two days (one day for research or special circumstances), two to seven days for the short-term ESs, and for the long-term ELs one to 12 months. If the occupant is terminating the sampling, the instructions should inform the occupant of when and how to terminate the sampling period. EC units integrate the radon (ion) signal permanently, so variations from these recommended measurement periods are acceptable to accommodate special circumstances as long as the final electret voltage for any measurement remains above 150 volts. In addition, the occupant also should be instructed to send the ES or EL to the laboratory as soon as possible, preferably within a few days following exposure termination.

At the end of the monitoring period, the ES or EL should be inspected for any deviation from the conditions described in the log book at the time of deployment. Any changes should be noted. The electret should be covered again using the mechanism provided.

2.3.9 Documentation

The reader should refer to Section 1.2.4 for the list of standard information that must be documented.

In addition, the serial number, type, and supplier of the chamber and electret, along with a code number or description which uniquely identifies customer, building, room, and sampling position, must be documented. If the temperature of the room in which the EC is analyzed after exposure is significantly different (more than 10°F) from the temperature of the room in which the EC was analyzed prior to exposure, those temperatures need to be recorded.

2.3.10 Analysis Requirements

In general, all ESs or ELs should be analyzed in the field or in the laboratory as soon as possible following removal from buildings. A background correction must be made to the radon concentration value obtained because electret ion chambers have a small response to background gamma radiation. If the temperature at the time of analysis is significantly different (more than 10°F) than at the time when the pre-exposure voltage was determined, a temperature correction factor may be necessary (consult the manufacturer). It is therefore advisable to measure voltages after the temperatures of the reader and detector have stabilized to a room temperature in which both pre- and post-exposure voltages have been measured.

2.3.10.1 Sensitivity. For a seven-day exposure period using an ES, the lower level of detection (LLD), as defined by Thomas (Thomas 1971) as the concentration that can be measured with a 50 percent error, is about 0.2 pCi/L. For an EL, the LLD is about 0.3 pCi/L or less for a three-month measurement. Note that this definition of LLD is different from that for radiation counting instruments, as defined for other methods by Altshuler and Pasternack (Altshuler and Pasternack 1963).

2.3.10.2 Precision. Precision should be monitored by using the results of duplicate detector analyses described in Section 2.3.11.3 of this protocol. This method can produce duplicate measurements with a coefficient of variation of 10 percent or less at 4 pCi/L or greater. An alternate measure of precision is a relative percent difference, defined as the difference between two duplicate measurements divided by their mean; note that these two measures of precision are not identical quantities. It is important that precision be monitored continuously over a range of radon concentrations and that a systematic and documented method for evaluating changes in precision be part of the operating procedures.

2.3.11 Quality Assurance

The quality assurance program for measurements with ES or EL detectors includes five parts: (1) calibration, (2) known exposure detectors, (3) duplicate (collocated) detectors, (4) control detectors, and (5) routine instrument checks. The purpose of a quality assurance program is to assure and document the accuracy and precision of the measurements and that the measurements are not influenced by exposure from sources outside the environment to be measured.

2.3.11.1 Calibration. Every ES or EL detector system (detectors plus reader) should be calibrated in a radon calibration chamber at least once every 12 months. Initial calibration for the system is provided by the manufacturer. Determination of calibration factors for ES or EL detectors requires exposure of detectors to known concentrations of radon-222 in a radon exposure chamber. Since ESs and ELs are also sensitive to exposure to gamma radiation (see Section 2.3.11.4), a gamma exposure rate measurement in the test chamber is also required.

The following guidance is provided to manufacturers and suppliers of EC services as minimum requirements in determining the calibration factor:

Detectors should be exposed in a radon chamber at several different radon concentrations or exposure levels similar to those found in the tested buildings (a minimum of three different concentrations).

A minimum of 10 detectors should be exposed at each level.

The period of exposure should be sufficient to allow the detector to achieve equilibrium with the chamber atmosphere.

2.3.11.2 Known Exposure Detectors. Anyone providing measurement services with ES or EL detectors should subject detectors with known radon exposures (spiked samples) for analysis at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. Blind calibration detectors should be labeled in the same manner as the field detectors to ensure identical processing. The results of the spiked detector analysis should be monitored and recorded and any significant deviation from the known concentration to which they were exposed should be investigated.

2.3.11.3 Duplicate (Collocated) Detectors. Anyone providing measurement services with EC devices should place duplicate detectors in enough houses to test the precision of the measurement. The number of duplicate detectors deployed should be approximately 10 percent of the number of detectors deployed each month or 50, whichever is smaller. The duplicate devices should be shipped, stored, exposed, and analyzed under the same conditions, and not identified as duplicates to the processing laboratory. The samples selected for duplication should be distributed systematically throughout the entire population of samples. Groups selling measurement services to homeowners can accomplish this by providing two detectors instead of one to a random selection of purchasers, with instructions to place the detectors side-by-side. Consideration should be given to providing some means to ensure that the duplicate devices are not separated during the measurement period. The analysis of duplicate data should follow the methodology described by Goldin (section 5.3 of Goldin 1984), by Taylor (Taylor 1987), or by the EPA (U.S. EPA 1984). Whatever procedures are used must be documented prior to beginning measurements. Consistent failure in duplicate agreement may indicate a problem in the measurement process and should be investigated.

2.3.11.4 Control Detectors for Background Gamma Exposure and Electret Stability Monitoring. Electrets should exhibit very little loss in surface voltage due to internal electrical instabilities. Anyone providing measurement services with ES or EL detectors should set aside a minimum of five percent of the electrets or 10, whichever number is smaller, from each shipment and evaluate them for voltage drift. They should be kept covered with protective caps in a low radon environment and analyzed for voltage drift over a time period similar to the time period used for those deployed in homes. Any voltage loss found in the control electrets of more than one volt per week over a three-week test period for ESs, or one volt per month over a three-month period for ELs, should be investigated.

ECs are sensitive to background gamma radiation. The equivalent radon signal in picoCuries per liter (pCi/L) per unit background radiation in microroentgens per hour (μR/hr) is determined by the manufacturer for three different types of EC chambers currently available. This is specific to the chamber and not to the electret used in the chamber. These parameters are 0.07, 0.087, and 0.12 for H, S, and L chambers, respectively. Depending upon the type of chamber employed in EC, one of these values must be multiplied by the gamma radiation level at the site (in μR/hr) and the product (in equivalent pCi/L) subtracted from the apparent radon concentration. The gamma radiation at the measurement site is usually taken from the EPA list of average background by State, as provided by the manufacturer. However, it can also be measured with an EC unit that is sealed in a radon-proof bag available from the manufacturer, or measured directly using appropriate radiation detection instruments. The latter step is necessary for accurate radon measurements at very low levels such as those encountered in the outdoor environment.

2.3.11.5 Routine Instrument Checks. Proper operation of the surface voltmeter should be monitored following the manufacturer's procedures for (1) zeroing the voltmeter, and (2) analyzing a reference electret. These checks should be conducted at least once a week while the voltmeter is in use.

Go to top

2.4 Protocol for Using Activated Charcoal Adsorption Devices (AC) to Measure Indoor Radon Concentrations

2.4.1 Purpose

This protocol provides guidance for using activated charcoal adsorption devices (AC) to obtain accurate and reproducible measurements of indoor radon concentrations. As referred to in this document, ACs are those charcoal adsorption devices that are analyzed by gamma scintillation (including open-faced canisters, diffusion barrier canisters, and diffusion bags). Charcoal detectors analyzed by liquid scintillation are covered under a separate protocol (see Section 2.5). Adherence to this protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce results representative of closed-building conditions. Measurements made under closed-building conditions have a smaller variability and are more reproducible than measurements made when the building conditions are not controlled. The investigator should also follow guidance provided by the EPA in "Protocols for Radon and Radon Decay Product Measurements in Homes" (U.S. EPA 1992c) or other appropriate EPA measurement guidance documents.

2.4.2 Scope

This protocol covers, in general terms, the sample collection and analysis method, the equipment needed, and the quality control objectives of measurements. It is not meant to replace an instrument manual but, rather, provides guidelines to be incorporated into standard operating procedures by anyone providing measurement services. Questions about these guidelines should be directed to the U.S. Environmental Protection Agency.

2.4.3 Method

ACs are passive devices requiring no power to function. The passive nature of the activated charcoal allows continual adsorption and desorption of radon. During the measurement period (typically two to seven days), the adsorbed radon undergoes radioactive decay. Therefore, the technique does not integrate uniformly radon concentrations during the exposure period. As with all devices that store radon, the average concentration calculated using the mid-exposure time is subject to error if the ambient radon concentration varies substantially during the measurement period.

The AC technique is described in detail elsewhere (Cohen and Cohen 1983, George 1984, George and Weber 1990). A device used commonly by several groups consists of a circular, six- to 10-centimeter (cm) diameter container that is approximately 2.5 cm deep and filled with 25 to 100 grams of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in but allows air to diffuse into the charcoal.

In some cases, the charcoal container has a diffusion barrier over the opening. For longer exposures, this barrier improves the uniformity of response to variations of radon concentration with time. Desiccant is also incorporated in some containers to reduce interference from moisture adsorption during longer exposures. Another variation of the charcoal container has charcoal packaged inside a sealed bag, allowing the radon to diffuse through the bag. All ACs are sealed with a radon-proof cover or outer container after preparation.

The measurement is initiated by removing the cover to allow radon-laden air to diffuse into the charcoal bed where the radon is adsorbed onto the charcoal. At the end of a measurement period, the device is resealed securely and returned to a laboratory for analysis.

At the laboratory, the ACs are analyzed for radon decay products by placing the charcoal, still in its container, directly on a gamma detector. Corrections may be needed to account for the reduced sensitivity of the charcoal due to adsorbed water. This correction may be done by weighing each detector when it is prepared and then reweighing it when it is returned to the laboratory for analysis. Any weight increase is attributed to water adsorbed on the charcoal. The weight of water gained is correlated to a correction factor, which is derived empirically by using a method discussed elsewhere (George 1984). This correction factor is used to correct the analytical results.

This correction is not needed if the configuration of the AC is modified to reduce significantly the adsorption of water and if the user has demonstrated experimentally that, over a wide range of humidity's, there is a negligible change in the collection efficiency of the charcoal within the specified exposure period.

AC measurement systems are calibrated by analyzing detectors exposed to known concentrations of radon in a calibration facility.

2.4.4 Equipment

ACs made specifically for ambient radon-monitoring can be obtained from suppliers or can be manufactured using readily available components. Some charcoal canisters designed for use in respirators or in active air sampling may be adapted for use in ambient radon monitoring, as described elsewhere (Cohen and Cohen 1983, George 1984).

The following equipment is required to measure radon using ACs:

- A charcoal container(s) sealed with a protective cover;
- An instruction sheet and sampling data sheet for the occupant, and a shipping container (along with a prepaid mailing label, appropriate; and
- A data collection log.

Laboratory analysis of the exposed devices is performed using a sodium iodide gamma scintillation detector to count the gamma rays emitted by the radon decay products on the charcoal. The detector may be used in conjunction with a multi-channel gamma spectrometer or with a single-channel analyzer with the window set to include the appropriate gamma energy window. The detector system and detector geometry must be the same used to derive the calibration factors for the device.

2.4.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The AC measurement should not be made if the occupant will be moving during the measurement period. Deployment should be delayed until the new occupant is settled in the house.

The devices should not be deployed if the occupant's schedule prohibits terminating the measurement at